Continental J. Earth Sciences 8 (1): 12 - 20, 2013 ISSN: 2141 – 4076
© Wilolud Journals, 2013 http://www.wiloludjournal.com
Printed in Nigeria doi:10.5707/cjearthsci.2013.8.1.12.20

HYDRO-GEOLOGICAL ISSUES AND CHALLENGES OF MANAGING TRANS-BOUNDARY AQUIFER SYSTEMS IN NIGERIA

H.O Nwankwoala
Department of Geology, University of Port Harcourt, Nigeria

ABSTRACT
People's lives and livelihoods depend on water. Maintaining secure water supplies for drinking, industry and agriculture would be impossible without groundwater, the largest and most reliable of all freshwater resources. The status of exploitation of the transboundary aquifer systems in Africa calls for an urgent mutually agreeable groundwater management plan to be put in place. This paper therefore, presents a clear picture of the hydrogeological conditions of the various groundwater regions/basins in Nigeria and examines the potentials of transboundary aquifer system and discusses the hydro-geological considerations and management options of trans-boundary aquifer resources with a view to producing a synoptic overview of the hydro-geological character in each groundwater basin. Monitoring network of boreholes for groundwater quality and quantity measurements would have to be put in place, particularly in zones considered to be critical because withdrawals are exceeding recharge or contamination is threatening groundwater quality. Central to any strategy, the evidence which requires systematic and prolonged data collection and rigorous analysis is very necessary. A long-term sustainable management and protection of groundwater resources in Nigeria is suggested.

KEYWORDS: Transboundary aquifer, groundwater, hydrogeological potentials, basins, Nigeria.

Received for Publication: 13/01/13 Accepted for Publication: 16/03/13
Corresponding Author Email: nwankwoala_ho@yahoo.com

INTRODUCTION

A typical trans-boundary aquifer includes a natural subsurface groundwater flow intersected by an international boundary such that water transfers from one side of the boundary to the other (Boukalova, 2001). A trans-boundary issue may arise when a water system, due to its geographical location or political conditions, falls partly or totally under the jurisdiction of two or more countries.

The significance of trans-boundary aquifers as a key resource has been further emphasized through the recent publication of the World Hydro-geological Map (IAH, 2003). Complete analysis of the number of aquifers that are trans-boundary has not been completed to date, however by analogy to the 261 trans-boundary rivers basins of the world, it is clear that a similar number, if not greater aquifers are shared by nations. Almost 40% of the world population lives in one or another trans-boundary water resources region (Almassy, and Buzas, 1999). A further confirmation of the wide distribution of trans-boundary aquifers can be gauged by the knowledge that there is a significant predominance of accessible fresh water from aquifers (over 90%) than from other sources. Groundwater is the water resource of critical importance for poverty alleviation, as it can be provided cheaply and usually nearest to the point of demand.

Aquifer systems, due to their partial isolation from surface impacts, on the whole contain excellent quality water. In many countries these systems have been fully assessed, evaluated and extensively used for municipal and other demands. Such resources represent a substantial hidden global capital that still needs prudent management. Competition for visible trans-boundary surface waters, based on available international law and hydraulic engineering is evident in all continents. However, the hidden nature of trans-boundary groundwater and lack of legal frameworks invites misunderstandings by many policy makers. Not surprisingly therefore, trans-boundary aquifer management is still in its infancy, since its evaluation is difficult, suffering from lack of institutional will and finance to collect the necessary information. Although there are fairly reliable estimates of the resources of rivers shared by two or more countries, no such estimates exist for trans-boundary aquifers (Almassy and Buzas, 1999).

Water is one natural resource that rarely has a substitute. The steady growth in world population coupled with the extension of irrigated agriculture and accelerated industrial development and other economic activities have put tremendous stress on the quality and quantity aspects of groundwater resources the world over (Maduabuchi, 2002). Available records show that the

This work by Wilolud Journals is licensed under a Creative Commons Attribution 3.0 Unported License.

Iullemeden aquifer system which serves as a veritable source of water supplies is being suggested to extensive use with the sinking of about 4,000 deep boreholes in the Sokoto basin in Nigeria. In the Chad Basin area, a myriad of boreholes sunk at random tap the various aquifers, particularly the Early Pliocene (Middle) Aquifers which has been extensively developed over the years. Though these multi-layered aquifer systems are generally under sustainable exploitation within most parts of the country, however, isolated cases of progressive decline in phreatic and piezometric surfaces are already manifest.

This paper, therefore discusses the hydro-geological settings as well as the major sedimentary aquifer systems (Sokoto Basin, Chad Basin and Dahomeyan Basin) that extends the Nigerian boundary. This paper also identifies persistent trans-boundary aquifer resource management problems and contributes to the improvement of the knowledge on the aquifers and suggested strategies that will aid in the sustainable development and management of the regionally shared aquifer systems.

HYDROGEOLOGICAL PROPERTIES/POTENTIALS OF DIFFERENT BASINS IN NIGERIA

Nigeria is located on the west coast of Africa, between latitudes 4^0 N and 14^0 N and between longitudes 2^0 E and 15^0 E. It is bound to the north by the Republic of Niger, while to the west and east, it is bound by the Republics of Benin and Cameroun respectively. The Bight of Guinea bounds it at the southern coast along a shoreline of 800 km. it occupies a land area of 923,800 km^2, with abundant groundwater resources, enough to cater for the needs of her teeming population of more than 140 million.

There is a very large groundwater potential in Nigeria, far greater than the surface water resources, estimated to be 224 trillion l/year (Hanidu, 1990). Rijswlk (1981) estimated groundwater resources at 0-50m depth in Nigeria to be 6 x $10km^3$ (6 $x10^{18}m^3$). However, from the eight aquifers in Nigeria (Akujieze, *et al.*, 2003), the Ajali Sandstone aquifer yields 7 - 10 l/s, the Benin Formation (Coastal Plain Sands) aquifer yields 6 - 9 l/s, the Upper aquifer 2.5 – 30 l/s, the Middle aquifer 24 – 32 l/s, the Lower aquifer with yields of 10 – 35 l/s (of the Chad Formation), the Gwandu Formation aquifer with yields of 8 – 15 l/s, the Kerrikerri Sandstone aquifer with yields of 1.25 – 9.5 l/s and the crystalline fluvio-volcanic aquifer with a 15 l/s yield in the Jos Plateau region; groundwater occurrence is not limited to only 50m b.g.l (below ground level). These eight mega regional aquifers have an effective average thickness range of 360m, with a thickness range of 15 – 3,000m at a depth range of 0 – 630m b.g.l with an average depth of 220m (Akujieze *et al.,* 2003).

Reserves of groundwater are considerable in large sedimentary basins, which cover some 40% of the country. The potential annual groundwater resources are estimated at 51.93 $x10^9m^3$, out of which the sedimentary basins account for 67% (FMWRRD, 1995).

The occurrence of groundwater is greatly influenced by the local geological conditions which ultimately control yields. Recharge to aquifers, which influences the safe yields of wells, depends on rainfall over the area. Thus, rainfall ultimately controls the amount of groundwater recovered from wells in any given locality (Offodile, 1979). The extent of amount of groundwater storage is not yet known, but available records indicate that major aquifers in Nigeria are located in the sedimentary deposit basins, which cover about 50% of the nation's land area. The remaining 50% is underlain by crystalline rocks of the basement complex.

Aquifers within the basement are limited, their thickness ranges from 16 – 180m, but depth of hand dug wells and boreholes are therefore seldom more than 60m with a variable average of static water level between 1 – 45m below the surface. This shallow depth coupled with the poor hydraulic conductivity, no doubt accounts for the general low yield of $1.0m^3$/hr (Nwaogazie, 1995). On the sedimentary deposits, groundwater resources usually occur either as confined aquifers with average piezometric level of 75 – 150m or unconfined aquifers with thickness varying from 15 – 100m (Nwaogazie, 1995).

Generally, the geology of Nigeria can be divided into two broad units (the Basement Complex and the Sedimentary basins). The basement complex rocks are located in the north central, western and eastern flank of the country. The sedimentary formations are found in the north-west (Sokoto Basin), north-east (Chad Basin) and the coastal plains (Dahomeyan Basin) where the aquifers extend beyond the boundary of the country.

SOKOTO BASIN

The Sokoto Basin, located in the Northwestern Nigeria is part of the larger Iullemeden basin which extends through Niger Republic to Mali. There are about 60, 000 km^2 (10%) of this basin within the Nigerian territory and it shares roughly 570 km boundary with the Republic of Niger (Maduabuchi, 2002). The states within the basin include Kebbi, Sokoto, Zamfara and parts of Katsina state.

The Sokoto Basin, up to 2000m consists of clastic sequences that rest upon the basement. Sequences of semi-consolidated gravels, sands, clay, some limestone and ironstone are found. Pumping test data carried out in the shallow aquifers in the area indicates transmissivity in the range of 200 – $5000m^2$/d and storage coefficients of 10^{-2} to 10^{-5} indicating semi-unconfined to confined conditions (Bassey *et al*., 1999). The yield of boreholes up to 20m depth is generally <2 l/s. The fluctuation of the water

This work by Wilolud Journals is licensed under a Creative Commons Attribution 3.0 Unported License.

table in fadama (low-lying) areas is about 2 – 3m throughout the year. The water table is lowest in June and highest in September at the end of the wet season. Precipitation in the area occurs within 3 – 5 months, giving short-lived but strong runoff. Stream discharge measurement values on the basin range from 9.64 x $10^8m^3/a$ – 7.13 x $10^9m^3/a$ (Anderson and Ogilbee, 1973).

The Sokoto Basin has five (5) major aquifers which are distinguishable on the basis of geological setting and geography:

(i) Gundumi Formation (Lower Cretaceous) includes river and lacustrine deposits, which contain comparatively coarser materials than any of the younger overlying formations of the Sokoto Basin.

(ii) Illo Group (Cretaceous), similar in lithology to the Gundumi Formation, includes non-marine cross-bedded pebbly sand and clay that underlie an area of about 6400km^2 in the southwestern part of the Sokoto Basin.

(iii) Rima Group (Upper Cretaceous) consists of a marine transgressive series of fine-grained sand and friable sandstone, mudstone, and some marly limestone and shale. North of the River Sokoto, the group is divided into three formations, the Taloka at the base, the Dukamaje in the middle, and the Wurno Formation at the top (Oteze, 1989a).

(iv) Sokoto Group (Paleocene) consists of a lower unit (the Dange Formation, which is basically a marine clay shale), an upper unit of light-grey and white-clayey limestone with modular crystalline limestone, known as the Kalambaina Formation.

(v) Gwandu Formation (Eocene) crops out over 13, 600km2 in the western third of the Sokoto Basin with sediments made up of interbedded semi-consolidated sand and clay. The Gwandu Formation unconformably overlies the Kalambaina Formation in the northern and central part of the basin. These aquifers remain the sole source of drinking water in most parts of the basin, as rainfall is sparse. According to Oteze (1989b), the Eocene-Miocene Gwandu Formation is the most prolific aquifer with an annual recharge exceeding 6.6 x 10^7m^3 and estimated groundwater storage of about 8.17 x $10^{12}m^3$.

The Mesozoic and Tertiary strata of the Sokoto part of the Illemmmeden Basin in Northwest Nigeria, comprise of inter-bedded sandstones, clays and limestones that dip to the northwest. These formations are capped by laterites and the sedimentary sequence includes the late Jurassic to Early Cretaceous Illo and Gundumi Formations, the Maastrichtian Rima Group, the late Paleocene Sokoto Group and the Eocene-Miocene Gwandu Formation (Fig.1). These were deposited during a series of overlapping marine trangressions. Over 1250 metres of sediments occur in the down-warped Sokoto Basin, unconformably overlying Precambrian Basement rocks (Adelana *et al,* 2008; Ngatcha *et al.,* 2008). Quaternary age alluvial deposits occur
along the course of the River Sokoto.

From available hydrological data, it has been estimated that the Rima River system between Sabon-Birni and Sokoto town loses an average of 4 x $10^8m^3/a$. A part of this water may be evaporated while the remaining infiltrates into the alluvium, and in turn recharges the aquifers. Recent quantitative estimation of groundwater recharge using chloride method indicates mean recharge is in the order of 19.6mm/a based on an annual rainfall average of 670mm from 1916 – 1993 in the Sokoto area, although rates can be highly variable in space and time. Results further show recharge around the Wurno and Goronyo areas as representing <1% of annual rainfall while areas outside this region (Argungu/Gwandu areas) 3.2% of annual rainfall recharges the groundwater. This sharp variation was attributed to local conditions of climate and lithology (Adelana *et al*., 2006).

This work by Wilolud Journals is licensed under a Creative Commons Attribution 3.0 Unported License.

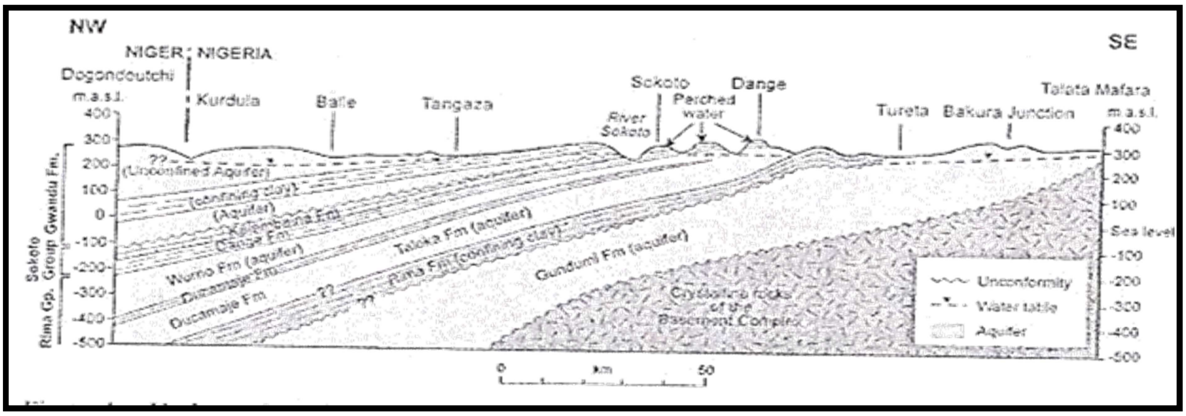

Fig. 1: Hygrogeological Cross Section Showing Sokoto Basin (Modified after Anderson and Ogilbee, 1973)

CHAD BASIN

The Chad Basin in Nigeria is located in the north-eastern part of the country, with an areal extent of about 152, 000km^2 representing only about 6.5 percent of the entire hydrographic basin which extends to Chad, Niger, Algeria, Libya, Sudan, Central African Republic and Cameroun. The Chad Basin covers Borno, Yobe and Jigawa states and parts of Kano and Bauchi states.

An inland lake within the Chad Basin, the lake Chad is surrounded by Nigeria, Niger, Chad and Cameroun and constitutes the main body of surface water in the basin. There are three (3) main drainage systems into the lake – the Chari-Logone River with headwaters in the Central African Republic and the Cameroun respectively. The other two originate from Nigeria and include the Komadugu-Yobe River which descends from the Bauchi plateau and river Yedseram from the Biu plateau. The Nigerian rivers are essentially ephemeral and account for about 10% of the total surface water input into Lake Chad.

The principal aquifers of the Chad Basin in Nigeria are the ones exploited and include (i) Quaternary (Upper) Aquifer (ii) Early Pliocene (Middle) Aquifer and (iii) Continental Terminal (Lower) Aquifer, as named by Barber and Jones (1960). Fig. 2 is a geological cross section showing the aquifers of the Chad Formation.

(i) Quaternary (Upper) Aquifer

The Upper Aquifer in most part of the area is within the superficial deposits, and extends across the entire outcrop of the Chad Formation. It is composed of alluvium and aeolian sands and gravel deposited during recent times. The thickness of the sands increases considerably north of the lake because of subsidence movements. The aquifer has been highly developed for domestic water supply, vegetable gardening and livestock watering through handdug wells and shallow boreholes (Maduabuchi, 2002).

Over the years, groundwater levels in the Upper Aquifer have been lowered, resulting in the deepening of wells. The aquifer is recharged largely through rainfall and occasional runoff. Transmissivity in the area ranged from 0.6 – 8.3 m^2/d with discharge of about 10^{5}m^3/d from the aquifer. Water quality is generally good with the exception of some zones affected by evaporates (polders from the lake) and few others of localized anthropogenic impact.

Around the type locality (Maiduguri), the Upper Aquifer includes not only a surface zone of recent sands with an unconfined water table, but deeper layers of sands of the Chad Formation complexly intercalated between clays, and are partially confined by the clays.

This work by Wilolud Journals is licensed under a Creative Commons Attribution 3.0 Unported License.

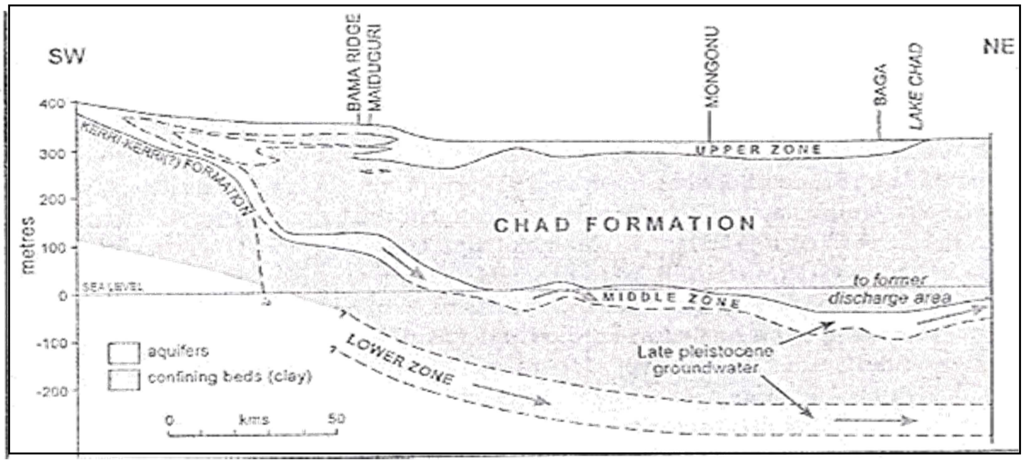

Fig.2: Geological Cross Section of Chad Formation (After Adelana *et al.*, 2008)

(ii) Early Pliocene (Middle) Aquifer
The Middle Aquifer is separated from the Upper Aquifer by a thick sequence of grey to bluish-grey clay in the range of 60 – 200metres. The aquifer is generally encountered at depths of about 240 – 380metres from the surface in many places and consists of sand beds with interrelated clays and diatomites. The sandy members are coarse, angular quatz grains with feldspar and mica contents. The thickness of the water bearing layer varies from 10 – 40 metres, with a mean transmissivity value of 360m^2/d.

The piezometric head of the aquifer has progressively declined and several wells in the aquifer have lost their free-flowing potentials. However, in 70% of the wells in the area, groundwater is still under artesian condition with piezometric heads increasing from Maiduguri towards the Lake Chad. The slope in piezometric heads is about0.015% in the NE direction. Abstraction from this aquifer is upwards of 10^5 m^3/d while free-flowing yield (uncontrolled discharge) is between 0.12 and 90 m^3/hr. Generally, the quality of the water is not as good as in the Upper as it is often more mineralized.

(iii) Continental Terminal (Lower) Aquifer
This aquifer consists of alternations of sand and clay and lies at depths of 450 – 650 m, with an average thickness of about 90 m in Maiduguri. Transmissivity value varies from 33 – 105 m^2/d. the piezometric surface slopes 0.115% in the North and North East Direction. Free flow varies from 7 – 17 m^3/hr while groundwater abstraction from the aquifer is about 0.41 x 10^5 m^3/d. The aquifer presently is the main source of water supply to Maiduguri metropolis. The piezometric head of the aquifer, usally between 3 – 6 m above ground level has also declined due to excessive development.

In the West and Northwest of Maiduguri, only the Upper aquifer exists, while the Middle aquifer is perched of discontinuous and the lower non-existent. Incidentally, in the Kanem region in Niger Republic, the quaternary sands lie directly on those of the the lower aquifer, forming a single aquifer with thickness often greater than 275 metres (Eberschweiler, 1993). Drilling in the basin revealed that the first and second aquifers thicken and thin out in places and in some cases disappear completely, hence not uniform in the basin. On the other hand, the lower aquifer is normally encountered at a consistent depth range of 450 – 650 m in the basin and relatively uniform and extensive with restricted spatial occurrence (Maduabuchi, 2002).

DAHOMEYAN BASIN
The Dahomey Basin (also called the Benin or Keta Basin in Nigerian literature) is a transboundary basin that extends from Ghana through Togo and Benin to Nigeria. The Niger Delta basin is separated by the Okitipupa Ridge (Omatsola and Adegoke, 1981).

The Basin constitutes part of a system of West African margin developed during a brief period of rifting in the late Jurassic to Early Cretaceous, associated with the Benin Trough Complex. It was accompanied by an extended period of thermally induced basin subsidence through the Middle to Upper Cretaceous to Tertiary times as the South American and African plate entered a drift phase. The onshore portion of the basin covers a broad arc-shaped profile approximately 600km^2, attaining a maximum width of 65km at the basin axis along the Nigerian border with the Republic of Benin. It narrows to about 25km west and eastwards. It is along its north eastern fringe (the Okitipupa Structure) that a band of tar sand (oil sand) and bitumen seepage occurs (Omatsola and Adegoke, 1981).

This work by Wilolud Journals is licensed under a Creative Commons Attribution 3.0 Unported License.

The Basin covers the southern areas of Lagos, Ogun and Ondo States in Nigeria and stretches into the neighbouring countries of Benin, Togo, Ghana and Ivory Coast. In the Keta basin, urbanization and over abtraction is substantially increasing (Banoeng-Yakubo *et al.*, 2003). Though geological continuity is inferred, therefore discussions here will relate to available data in respect of the Nigerian sector of the basin.

The rocks of the Dahomey basin are mainly sands, clays and limestones (Jones and Hockey, 1964; Longe *et al.*, 1987). The basement complex which forms the basement rocks in the basin is overlain in succession by the Cretaceous Abeokuta Formation which is sandy with interbedded shales and limestone formation. Following it is the Tertiary Ewekoro Formation comprising of limestone, clays and shales and the Ilaro Formation consisting of clays and shales followed by the poorly sorted Coastal Plain Sands and Recent Alluvial Deposits. The latter which consists of lithoral and lagoonal sediments of the coastal belt is characterized by Mangrove (saltwater) and freshwater swamps where aquifers, though readily recharged by copious rainfall are however vulnerable to saline water intrusion.

The lithological disposition of the aquifers gives rise to artesian and sub-artesian conditions in places. In the Lagos metropolitan area, the Coastal Plain Sands were the major aquifers exploited in the past but drilling for water supply over the past decade target the deeper Abeokuta Formation. This is because of excessive drawdown (progressive decline in head) associated with boreholes tapping the phreatic aquifers of the Coastal Plain Sands and the consequent problem of saline water intrusion already manifest in some localities. Salt water intrusion into the Recent Sediments aquifers occurs beneath a freshwater lens in a belt stretching from the coastline to a distance of about 5km in some places. Saltwater intrusion occurrence in the confined aquifers of the Coastal Plain Sands in a zone stretching from Apapa to Lekki within the Lagos metropolis is a serious issue. The saltwater bearing sands overlie freshwater aquifers which are exploited by boreholes. In the eastern part of the represented by Akodo, the freshwater aquifers in the Coastal Plain Sands are sandwiched between saltwater-bearing sands. The Coastal Plain Sands in a zone between Lekki and Akodo around Lakowe estimated to be about 20km wide consists predominantly of clay with only about 60m of sand overlying about 240m of clay unlike the other areas of the basin where sand represents between 70 – 95% of about 300m thick horizon (Oteri and Atolagbe, 2003).

The northern part of the coastal sedimentary formations contains interbedding sequences of shales and aquifers are mostly unconfined. The average depth range to water table is 20m – 300m while the average depth to confining layer is about 150m. The specific capacity ranges from 60 to 58.5 l/h/m. the average yield is 50 l/s.

The significantly undulating surface relief makes the Niger Delta a hydrogeologically shallow watershed as described by Toth (1963). Thus, the great quantities of water entering the region from rainfall and streams into the shallow aquifers in the north, discharge in depth beyond the coast. The greater part of the sediment is therefore flushed and groundwater is rarely stagnant except in those places where saline, presumably connate water entrapped in aquicludes, persist in depth. Such a condition is speculated at Borokiri- Port Harcourt, Buguma, Bille, Kulama, Bonny and Akasa in Rivers State, eastern Niger Delta (Oteri, 1988).

The Niger Delta is a coastal arcuate delta of the River Niger covering an area of about 75,000km^2. The subaerial Niger Delta has an extensive saline/brackish mangrove swamp belt separated from the sea by sand beach ridges for most of the coastline. Water supply problems relating to salinity are confined to the saline mangrove swamp with associated sandy islands and barrier ridges at the coast. Geologically, rocks of the Niger Delta are subdivided into three formations which are Akata, Agbada and Benin Formations (Short and Stauble, 1967). The Benin Formation consisting predominantly of massive highly porous sands and gravels with locally thin shale/clay interbeds forms a multi-aquifer system in the delta (Etu-Efeotor and Akpokodje, 1990; Etu-Efeotor & Odigi, 1983; Odigi, 1989). Many boreholes have been drilled into the aquifers of the Benin Formation yielding good quality water but many have also been abandoned due to high salinity (Amadi and Amadi, 1990; Ngerebara and Nwankwoala, 2008). The aquifer in the Recent Sediments is the water table aquifer in coastal barrier islands and sandy islands within the mangrove swamps. It could be as thick as 30m in some barrier islands such as Fishtown in Bayelsa State. This aquifer provides freshwater for many rural communities in the Niger Delta. Oil and gas are produced from sand reservoirs in the Agbada Formation while the Akata Formation consists of uniform shale rocks.

Overlying the Benin Formation are the Quaternary deposits which are 40 - 150 m thick, an unconfined aquifer sequence comprising rapidly alternating sequences of sand and silt/clay, (Table 1), with the latter becoming increasingly prominent seawards (Etu- Efeotor and Akpokodje, 1990).

(cc) BY
This work by Wilolud Journals is licensed under a Creative Commons Attribution 3.0 Unported License.

Table 1: Quaternary deposits of the Niger Delta (after Etu-Efeotor and Akpokodje, 1990)

Geologic Unit	Lithology	Age
Alluvium	Gravel, Sand, clay, silt	
Freshwater Backswamp, meander belt	Sand, clay, some silt, gravel	
Saltwater Mangrove Swamp and backswamp	Medium-fine sands, clay and some silt	Quaternary
Active/abandoned beach ridges	Sand, clay, and some silt	
Sombreiro-warri deltaic plain	Sand, clay, and some silt	

STRATEGY FOR SUSTAINABLE TRANSBOUNDARY AQUIFER RESOURCES MANAGEMENT

The immense diversity of aquifer types and their configurations suggests that no uniform approach is likely to apply to all transboundary aquifers. The most serious constraints in the management of transboundary aquifers and in the performance of water sector generally are: (i) the lack of clear definition of hydrogeological unit that could facilitate sustainable groundwater management; (ii) the non conformance of basin boundaries to the principles of river catchment, geological unit and hydrogeological characteristics of the underlying rock formations; (iii) the relatively small budget made available for water resources administration, infrastructure development and operations. Generally, persistent transboundary aquifer resource management problems include:

(i) Poor prediction of aquifer yields on one or either side of the national boundary;
(ii) High variability in transboundary aquifer properties and therefore high uncertainties;
(iii) Presence of unutilized or under-utilized groundwater resources on or other side of the national boundary;
(iv) Conflicting demands for the transboundary aquifer resource – such as between irrigation and industrial uses;
(v) Significant environmental concerns arising from current water management practices;
(vi) High likelihood that current transboundary aquifer management practices are depleting the resource, either through over-exploitation or by pollution.

Presently, there is a very little international experience in the approaches needed for transboundary aquifer resources management. Many strategies/actions are required with respect to basin boundary system to move from concept to reality with Integrated Water Resources Management (IWRM). The Lake Chad Basin Commission (LCBC) with headquarters in N' Djamena (Chad) has already series of principles, policies, general water laws, water administration regulations and basin oriented water laws. The establishment of similar commissions and the strengthening of existing ones are advocated. Such commissions will provide opportunities for information and risk-sharing, facilitate pooling of technical and financial resources, thereby reducing the burden on individual countries. Central to any strategy, the evidence which requires systematic and prolonged data collection and rigorous analysis is very necessary. Any sustainable suggestion towards the improvement of water resources management in the region must include but not limited to the following:
s

(i) Re-introduction of long-term hydrological observations and instigation of new data collection on water use, irrigation and agriculture lands, water sediment deposits, industrial demands, urban development, recharge, hydraulic properties as well as groundwater/surface water interaction;
(ii) Introduction of serious measures aimed at reducing land erosion, and consequent siltation of some basins and the existing hydro-agricultural infrastructure;
(iii) Enforcement of land-use regulations to reduce the contamination of water resources aimed at helping transboundary negotiations;
(iv) Protection of groundwater resources to safeguard long-term use and balance the demands of economic development with ecosystem conservation;
(v) Regional studies of hydrogeology, hydraulic properties, regional flow system and water quality that cross political boundaries;
(vi) Serious discussion and agreement on a common strategy for groundwater exploitation and equitable sharing across borders;
(vii) Greater integration of the relevant information systems, e.g hydrology, hydrogeology, water quality, land use, sediment transport etc;
(viii) Moving away from conventional basin system and develop new approaches that will belong to a common geographical unit that does not recognize political boundaries;
(ix) Promoting public awareness raising programmes for water users, planners and policy decision makers at all levels, and emphasizing a participatory approach involving the general public in water management.

This work by Wilolud Journals is licensed under a Creative Commons Attribution 3.0 Unported License.

CONCLUSION

There is no doubt that groundwater is vital natural resource for the reliable and economic provision of safe water supplies in both urban and rural environment. Quite unfortunately, in spite of the fundamental role groundwater plays in human well being, as well as that of many ecosystems, it is yet to be fully appreciated and adequately managed and protected, both within the country and regionally. It is a well known fact that groundwater basins are difficult to govern and manage, partly because of poor information, and also because of poor visibility of the resource, the need for reliable data and information in support of water resource planning is central to any strategy. Technology, knowledge transfer and sound research cooperation should receive sufficient attention at the regional scale for any meaningful solution of regional problems.

More importantly, environmental issues such as biodiversity, climate change, poverty alleviation, conflict prevention, ethical development of transboundary aquifers as well as non-traditional or specific uses like CO_2 sequestration and waste disposal is vital for sustainable development of transboundary aquifer resources. Inter-governmental cooperation and communication, joint aquifer resource monitoring strategy, joint (or parallel) development-management institutions as well as joint water user associations will go a long way in this effort.

REFERENCES

Adelana, S.M.A; Olasehinde, P.I and Vrbka, P (2006). Identification of groundwater recharge conditions in crystalline basement rock aquifers of the southwestern Nigeria. In: Recharge systems for protecting and enhancing groundwater resources, IHP-VI, Series on Groundwater No.13, 649 – 655, UNESCO, Paris.

Adelana, S.M.A; Olasehinde, P.I; Bale, R.B; Vrbka, P; Edet, A.E and Goni, I.B (2008). An overview of the geology and hydrogeology of Nigeria. In: Adelana, S.M.A & MacDonald, A.M (Applied Groundwater Studies in Africa), Vol.13, CRC Press/Balkema. pp171 – 197.

Akujieze, C.N; Coker, S.J.L and Oteze, G.E (2003). Groundwater in Nigeria – a millennium experience – distribution, practice, problems and solutions. *Hydrogeology Journal*, Vol.11, pp259 – 274.

Almassy, E and Buzas, Z (1999). Inventory of transboundary groundwaters. UN ECE Task Force on Monitoring and Assessment. Task Force Secretariat Leystad, The Netherlands. Vol. No. 1 of 4.

Amadi, U.M.P and Amadi, P.A (1990). Saltwater migration in the coastal aquifers of Southern Nigeria. *J. Mining Geol*. 26(1), pp35-44

Anderson, H.R and Ogilbee, W (1973). Aquifers in the Sokoto Basin, Northwestern Nigeria, with a description of the general hydrogeology of the region. Geological survey Nigeria. Water Supply Paper, 1757 – L.

Barber, W and Jones, D.G (1960). The geology and hydrology of Maiduguri, Bornu Province. Record of the Geological Survey Nigeria.

Bassey, J.O; Maduabuchi, C.M; Onugba, A; Verhagen, B.T and Vrbka, P (1999). Preliminary results of hydrogeological and isotopic research in the Rima River Basin, NW Nigeria. *Water Resources*, Vol.10, pp31 – 37.

Boukalova, Z (2001). Integrated international groundwater monitoring and management. In: Hydrogeological challenges in Transboundary Water Resources Management. International Conference, Koblenz, Germany, Hydrogeological Challenges in Transboundary Water Resource Management, Conference Proceedings, pp465 – 470.

Eberschweiller, C (1993). Monitoring and management of groundwater resources in the Lake Chad Basin. Report published by Lake Chad Basin Commission.

Etu-Efeotor, J.O and Akpokodje, E.G (1990). Aquifer systems of the Niger Delta. *J. Mining Geol.* Vol.26 (2), pp279-285

Etu-Efeotor, J.O and Odigi, M.I (1983). Water supply problems in the Eastern Niger Delta. J. *Mining Geol*., Vol.20(1& 2), pp183-193

FMWRRD (1995). The study on the National Water Resources Master Plan. Japan International Cooperation (JICA) and Federal Ministry of Water Resources and Rural Development, Federal Republic of Nigeria, Abuja.

This work by Wilolud Journals is licensed under a Creative Commons Attribution 3.0 Unported License.

Hanidu, J.A (1990). National growth, water resources and supply strategies in Nigeria in the 1990's. *Water Resources Journal of the Nigerian Association of Hydrogeologists*, Vol.1, pp1-6.

IAH (2003). World Hydrogeological Map – Prepared by the IAH Commission on Mapping in collaboration with BGR, UNESCO and IGCP. (www.iah.org)

Jones, H.A and Hockey, R.D (1964). Geology of parts of South-Western Nigeria. Bull. Geological Survey of Nigeria. No.31

Longe, E.O; Malomo, S and Olorunniwo, M.A (1987). Hydrogeology of Lagos metropolis. *Journal of African Earth Sciences*, Vol. 6, pp 163 – 174.

Maduabuchi, C.M (2002). Case studies on transboundary aquifers in Nigeria. Proceedings of International Workshop, Tripoli, Libya, 2 – 4 June, 2002.

Ngatcha, B.N; Mudry, J and Leduc, C (2008). Water Resources management in the Lake Chad Basin: Diagnosis and Action Plan. In: Adelana, S.M.A & MacDonald, A.M (Applied Groundwater Studies in Africa), Vol.13, CRC Press/Balkema. pp65 – 84.

Ngerebara, O.D and Nwankwoala, H.O (2008). Groundwater potentials in the offshore Niger Delta environment, Nigeria. *Electronic Journal of Environmental Hydrology*, Vol. 16, Paper 28, http//www.hydroweb.com

Nwaogazie, I.L (1995) "Water Resources Development in Nigeria: A Global Outlook? Proceedings of the 8th Annual Conf. On Environmental considerations in Water Resources Development, Nigeria association of Hydrogeologists (nah), Hotel Presidential, Port Harcourt, November 19-23rd ,1995.

Odigi, M.I (1989). Evaluating groundwater supply in Eastern Niger Delta, Nigeria. *Journal of Mining Geology*, Vol.25, pp 159-164

Offodile, M.E (1979). Water Resources Policy, Working paper on Policy, on Nigeria Water Resources Development, Unpublished paper from the Chairman of the NMGS Committee on Water Resources Policy.

Omatsola, M.E and Adegoke, O.S (1981). Tectonic Evolution and Cretaceous Stratigraphy of the Dahomey basin. *Journal Min. & Geology*, 18 (1), 130 -137

Oteri, A.U (1988). Electric log interpretation for the evaluation of saltwater intrusion in the eastern Niger Delta. *Hydrol. Sciences Journal* 33(1/2), 19 – 30.

Oteri, A.U and Atolagbe, F.P (2003). Saltwater Intrusion into Coastal Aquifers in Nigeria. Paper presented in the 2nd International Conf. on Saltwater Intrusion and Coastal Aquifers – Monitoring, Modelling and Management, Merida, Yucatain, Mexico, March 30 – April 2, 2003.

Oteze, G.E (1989a). Recharge Characteristics of Rima aquifers, Sokoto Basin. Water Resources, Vol.1, pp154 – 160.

Oteze, G.E (1989b). The hydrogeology of the North-Western Nigeria Basin. In: Kogbe, C.A (ed.) Geology of Nigeria. Rock View (Nigeria) Limited, Jos, Nigeria. Pp455 – 472

Rijswlk, K (1981). Small community water supplies. IRC Technical Paper Series, No.18. The Netherlands.

Short, K.C and Stauble, A.J (1967). Outline geology of the Niger Delta. *Bull. Am. Ass. Petrol Geol*. 54:761 – 779

Toth, J (1963). A theoretical analysis of groundwater flow in small drainage basins. *Jour. Geophy. Res.*, Vol. 68, pp 4795-4812

This work by Wilolud Journals is licensed under a Creative Commons Attribution 3.0 Unported License.